14 The Ordesa and Monte Perdido National Park, Central Pyrenees

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Abstract

The Ordesa and Monte Perdido National Park was created in 1918 and enlarged in 1982 to highlight and protect spectacular high mountain relief dominated by limestone. Alpine tectonics resulted in the piling-up of south-verging thrust sheets leading to the thick sedimentary successions exposed in impressive vertical cliffs. The presence of massive limestones has favoured the development of deep canyons and karst landforms, including karren, dolines, and caves with large shafts. Quaternary glaciations contributed to increase the geomorphic diversity, forming cirques and stunning U-shaped valleys. Small glaciers from the Little Ice Age still remain on the north-facing slopes of the Monte Perdido. Periglacial processes in the most elevated areas of the National Park, as well as erosion in thick soils developed on marly limestone have produced unique geomorphological features.

Keywords

National Park • Limestone • Canyon • Karst relief • Glaciers

14.1 Introduction

The Ordesa and Monte Perdido National Park (OMPNP) is an impressive mountain area in the central Pyrenees mostly underlain by limestone bedrock. The elevation of the mountains commonly exceeds 3,000 m a.s.l., and the landscape is largely controlled by the geological structure, reflecting also the impact of Quaternary glaciations, and the influence of past human activity. Its relief, characterised by dramatic vertical cliffs, deep canyons, U-shaped valleys, waterfalls, avalanche tracks and active glaciers, was the most important factor for the declaration of National Park in 1918. The protected area was originally 2,100 ha, but the enlargement of the National Park in 1982 provided protection for a total area of 15,608 ha. The OMPNP represents a typical high mountain landscape dominated by calcareous formations and affected by intense glacial erosion. The relief of the OMPNP provides the opportunity to study the altitudinal zonation of different landforms and geomorphic processes, as well as the role played by snow and ice in the past and present morphogenesis. Other environmental values (biodiversity, endemic species) reinforce the exceptional importance of the area.

Geomorphology has been one of the most intensively studied topics in the Pyrenees, mainly in relation to the glacial landforms and landscape evolution. Nevertheless, the OMPNP has been the subject of a limited number of geomorphological studies, beyond general descriptions in guides and popular books. A small part of the study area, the Marboré Cirque, has been the focus of various studies on periglacial and glacial landforms, including classical publications by Hernández-Pacheco and Vidal-Box (1946) and

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Barrère (1952). Barrère (1971) also published a geomorphological map of the Broto area in the context of a regional geomorphological map of an extensive sector of the Central Pyrenees. A part of the OMPNP was included in the Broto map, particularly the canyons of Ordesa, Añisclo, and Escuaín. Nicolás-Martínez (1981) provided more detailed information on the Marboré Cirque. García-Ruiz and Arbella (1981) studied soil erosion and shallow landsliding in the deep soils that cover the mid-altitude areas of the OMPNP. Martí-Bono and García-Ruiz (1993) produced a short report on the extent of the Quaternary glaciers, and García-Ruiz and Martí-Bono (2001) published a geomorphological map of the park, accompanied by a description of the most significant landforms. Various reports have referred to the present-day glaciers (e.g. Chueca et al. 2002) and the environmental evolution of the OMPNP during the last thousands years based on sediment cores from high mountain lakes (Oliva-Urcia et al. 2013; Salazar-Rincón et al. 2013).

This chapter synthesises historical and recent information on the geomorphology of the OMPNP, overviews the main features of its evolution, including structural, glacial, periglacial, and karst landforms, and highlights soil degradation processes in this unique protected area.

14.2 Geographical and Geological Setting

The OMPNP is located in the Central Spanish Pyrenees and comprises several valleys (Fig. 14.1): Arazas (also known Ordesa Valley), Bellos (Añisclo Valley), the Upper Cinca Valley (Pineta Valley), and Yaga (Escuaín Valley). Many peaks exceed 3,000 m a.s.l.: Monte Perdido (3,355 m), Cilindro (3,322 m), Marboré (3,247 m), Soum de Ramond (3,263 m). The Monte Perdido Massif, located on the main drainage divide, dominates the landscape. The Cinca River flows at the foot of the northern side of the massif, whereas the other rivers (the Arazas, Bellos, and Yaga rivers) drain the southern slopes. The Monte Perdido Massif is a part of the Inner Sierras, which is one of the main structural units of the southern Pyrenees. The formations exposed in the Inner Sierras correspond to Cretaceous–Eocene limestones, marly limestones, and sandstones. The compressional structural style is characterised by stacking of south-verging thrust sheets, locally affected by overturned folds (e.g. Cilindro Peak). The nappes were emplaced during the Alpine development of the Pyrenean orogeny, resulting in the development of limestone and sandstone piles thousands of metres thick. South of the Inner Sierras, the bedrock mostly consists of Eocene flysch facies, with the typical alternation of thin sandstone and marl beds. Here, the topography is gentler, with rounded divides and hillslopes displaying continuous profiles.

The climate shows predominantly Mediterranean influences: Atlantic effects barely reach the Central Pyrenees. The Góriz weather station (2,220 m a.s.l.) has recorded precipitation averaging 1,850 mm annually, the majority of which occurs in autumn and spring. Autumn rainstorms can be very intense, with more than 650 mm recorded in three days. The mean annual temperature at Góriz is approximately 4 °C, with three months (January, February, and March) having temperatures below 0 °C. The average temperature exceeds 10 °C between June and September. The 0 °C isotherm during the coldest period (November–May) is located at 1,603–1,670 m a.s.l. and thus includes most of the study area. This explains why, in spite of the low average winter precipitation, snowfall and snowmelt have a marked hydrological and geomorphological influence. Nevertheless, studies have confirmed a decline in the influence of snow in recent decades, related to a decrease in winter precipitation (López-Moreno 2005).

Altitude and topography were major limitations for agricultural use in the OMPNP. Beech tree (*Fagus sylvatica*) forests dominate in the Ordesa Valley, while mixed forests tend to prevail in the Añisclo and Escuaín valleys. Mixed stands of pine (*Pinus sylvestris*) and beech form dense forests below 1,800 m on the flysch slopes. The upper forest level is colonised by *Pinus uncinata*, which is well adapted to low winter temperatures, snow accumulation, stony soils, and steep slopes. Nevertheless, the upper forest limit is in most cases artificial, due to the removal of forest communities to enable the expansion of summer grasslands. Above 2,400–2,500 m vegetation is sparse because of the extreme climatic conditions.

14.3 Landforms

The complex and impressive relief of the OMPNP records a long geomorphological history mainly controlled by structural and climatic factors. The most outstanding landforms are largely determined by the distribution of the different lithologies and their structure, whereas fluvial and glacial processes have generated some of the best known geomorphic features of the OMPNP.

14.3.1 Structural Landforms: Cliffs and Canyons

The geology of the OMPNP and surrounding areas is characterised by the superposition of various thrust sheets, and the consequent piling-up of thick successions consisting mainly of limestone and, secondarily, sandstone and marly limestone (Ríos et al. 1982, 1989). Four nappes bounded by thrusts largely concordant with the strata have been identified. Some of these thrust structures display recumbent

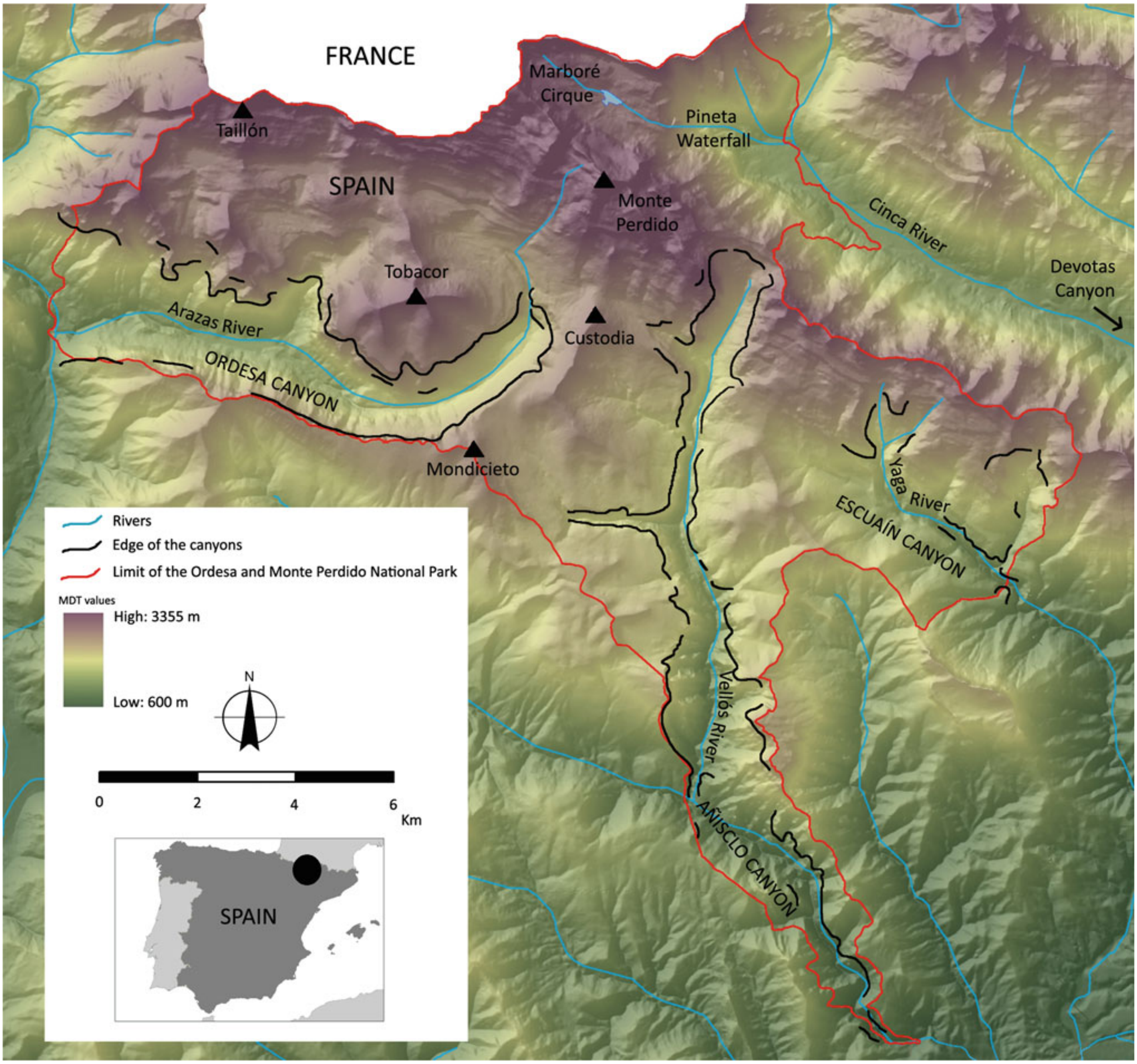

Fig. 14.1 The Ordesa and Monte Perdido National Park

anticlines at their front typically associated with nearly vertical limestone cliffs. Some sections display stacked overturned folds forming a peculiar cascade-like structure of folds. The sub-horizontal attitude of the thrusts and the limbs of the associated recumbent anticlines provide a false impression of a very simple horizontal structure, consisting of massive limestone with intercalations of sandstone beds. Structural landforms are common in the landscape. High and laterally extensive cliffs are abundant, reflecting the high strength of the bedrock; particularly good examples include the huge limestone escarpment of the Monte Perdido Massif (Fig. 14.2) and the precipitous walls of the canyons of Añisclo (Bellos River), Ordesa (Arazas River), and Escuaín (Yaga River).

The Añisclo, Ordesa, and Escuaín canyons have developed due to a long process of fluvial downcutting into a pre-existing relatively horizontal topography currently situated at 2,000–2,200 m a.s.l. The slopes of the canyons faithfully reproduce the resistance of the various lithological units, with successive vertical cliffs separated by slopes covered by scree (Fig. 14.2). In the case of the Ordesa Canyon, the valley has been carved through the pile of thrust sheets creating a tectonic window, like in the Añisclo Canyon. A number of cuestas have developed on each side of the

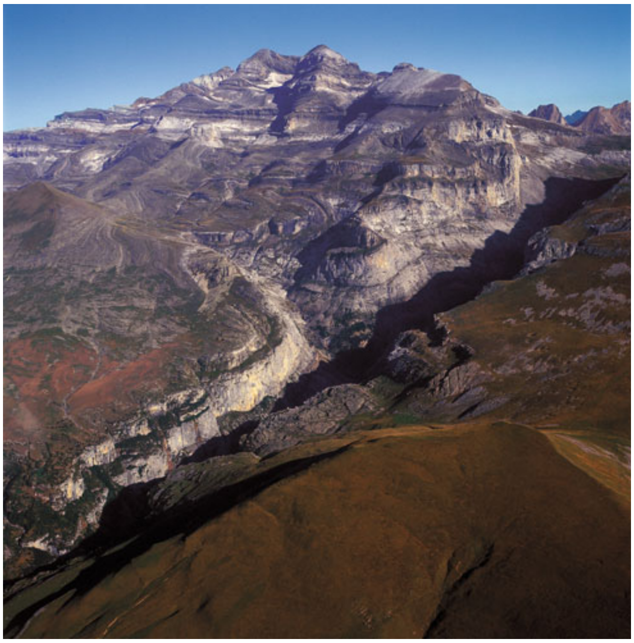

Fig. 14.2 The Monte Perdido Massif and the Añisclo canyon. *Photograph* Fernando Biarge

Fig. 14.3 Alpine karst landscape near the Góriz Shelter. *Photograph* Fernando Biarge

Añisclo Canyon, corresponding to the limbs of a N–S valley-centred anticline. Some of the tributaries developed short and steep hanging valleys with waterfalls associated with knick points (e.g. the Cotatuero and La Pardina valleys).

On the north-facing slopes of the Monte Perdido Massif, the Marboré Cirque is underlain by synclinorium-like structure, where alternating limestone and sandstone outcrops are evident, with small *cuestas* and depressions in the bottom of the cirque. The Pineta or Cinca waterfall, of approximately 1,000 m in height, falls into the Pineta Valley. To the southeast, the canyon of the Escuaín Valley is relatively modest in size, although the glacial cirques of Gurrundué and La Sarra have dramatic cliffs.

14.3.2 Karst Landforms

Surface karst landforms are common, including extensive karren, dolines, shafts, and sinks mainly formed by surface water. The Sierra de las Cutas, the flat areas near the Góriz Shelter, the sub-horizontal structural surfaces in the vicinity of the Añisclo Canyon, the reliefs immediately to the south of the Taillón and Casco peaks, and the right margin of the Escuaín Valley are among the many sites that display outstanding examples of karst topography and hydrology. In general, the most widespread landform corresponds to the structural karren (*kluftkarren*), mainly related to the solutional widening of stratification planes and joints. The result is a complex network of grikes that may reach more than 1 m in depth. In some places, particularly on sandy limestone, extreme dissolution controlled by discontinuity planes has resulted in isolated limestone boulders of capricious shapes (e.g. close to the Llano del Descargador; Fig. 14.3). On steep slopes underlain by massive limestone with a low density of joints, solution flutes (*rillenkarren*) is the dominant karren type. Small dolines are also relatively common and tend to cluster following fault lines.

The karren and small dolines are relatively recent, since they are located in areas covered by glaciers in the Upper Pleistocene. Some collapse dolines, particularly near the Góriz Shelter, have formed recently or are currently enlarging as the fresh appearance of their steep sides suggests. A small polje is recognisable in the La Estiva platform. Large depressions of mixed glacial and karstic origin, locally termed *llanos* (Descargador, Millaris, and Salarons *Llanos*) have developed on marly limestones and are partially filled by torrential deposits (Barrère 1964; García-Ruiz and Martí-Bono 2001). Downstream of each *llano*, a large doline has developed on grey, massive limestone, probably favoured by structural discontinuities associated with the underlying recumbent fold.

Surface water flow is generally absent, except in the main rivers and in some springs (the Fuen Blanca and Cola de Caballo wells). Throughout the OMPNP, most of the snowmelt and rainfall waters infiltrate almost immediately into the karstified bedrock. Underground drainage is favoured by a well-developed network of caves. Approximately 40 caves at altitudes >2,500 m remain iced for most of the year (e.g. the Casteret Cave).

14.3.3 Glacial Landforms

The high altitude of the OMPNP explains the importance of Quaternary glaciers in the evolution of the relief. Large ice masses developed in the cirques near the divides in the Monte Perdido Massif and descended towards the main valleys. The cirques on the southern slopes of the massif are well developed, with steep walls and frequent structural scarps. The large Marboré cirque, on the northern face of the Monte Perdido Peak, displays a structurally controlled overdeepened basin currently occupied by the Marboré Lake. Small-scale erosional glacial landforms (polished surfaces, striations, *roches mutonnées*) are absent due to limestone dissolution, except in the recently deglaciated surfaces at the front of the present-day glaciers.

The U-shaped Arazas and Añisclo valleys show the typical effects of glacial erosion at a large scale, formerly occupied by large ice tongues >400 m thick. The more rapid glacial erosion in these trunk valleys led to the development of hanging glacial valleys in the lateral tributaries, particularly the Salarons, Carriata, and Cotatuero valleys. The Arazas Valley also constitutes a hanging valley, with the Molineto waterfall at the confluence with the Ara Valley. In the Arazas glacial valley, the landscape locally has a conspicuous structural imprint, like in the Gradas de Soaso, a series of waterfalls developed on subhorizontal Maastrichtian sandstone. Other changes in the longitudinal profile reflect the presence of hard limestone outcrops, resulting in dramatic waterfalls, including the Cola de Caballo, Estrecho, Abanico, and Torrombotera in the Arazas Valley.

Glacial sediments are relatively scarce in the OMPNP. Remnants of old glacial deposits are visible on the left margin of the Añisclo Valley, perched at approximately 300 m above the valley bottom. No clear end moraines have been found in the Añisclo glacial valley, the terminal area of which would be at approximately 900 m a.s.l., near the San Urbez bridge. In the Escuaín Valley, the end moraines belonging to the Glacial Maximum are located at 1,400 m a.s.l. In the Arazas Valley, most of the moraine deposits belong to recession glacial stages and are located near the cirques. On the northern side of the Monte Perdido Massif, the Marboré Cirque has abundant glacial deposits from the Little Ice Age (LIA) (Fig. 14.4). A chaotic deposit composed of grey limestone blocks forms the front of a large rock avalanche, although it was considered to be a Late Glacial moraine (Nicolás-Martínez 1981). Beyond the OMPNP, the Cinca Valley has other glacial deposits at the foot of the Marboré Cirque, and on the left side at Espierba, 400 m above the valley bottom. The glacier ended at Salinas, next to the confluence with the Cinqueta Valley, upstream the Devotas Canyon (Martí-Bono and García-Ruiz 1993). Lewis et al. (2009) dated the last glacial maximum (LGM) at the front of the Cinca glacier at 62.7 ± 3.9 ka. The Ara Valley, into which the Arazas River flows, also has major lateral moraines associated with moraine-dammed lake basins (the Diazas and Buesa glacio-lacustrine deposits). The end moraines of the LGM are located several kilometres downstream, near Sarvisé. In the La Larri paleolake, which is located in a tributary of the Cinca Valley, sedimentation started prior to 35 ka (Salazar-Rincón et al. 2013), confirming that the glacial maximum in the Pyrenees occurred earlier than in mountains of central Europe. The age of the top of the lacustrine sediment of the La Larri paleolake is ca. 13 ka, suggesting that the main Cinca glacier had already retreated to the Balcón de Pineta area during the Younger Dryas and the transition to the Holocene.

The sediments retrieved from Marboré Lake reveal that the lake basin was deglaciated during the Younger Dryas. The sedimentation rate has been constant (0.45 mm year^{-1}) over the last 12.7 ka (Oliva-Urcia et al. 2013). With the onset of the Holocene, there was a clear increase in biological productivity in the lake. The most significant change during the Holocene occurred at approximately 5–4.4 ka and suggests a decrease in humidity. Increased run-off and sediment delivery, and higher productivity occurred during the LIA.

14.3.4 Periglacial Processes

Throughout the OMPNP scree slopes occur at the foot of the cliffs, forming steep accumulations of angular gravel- and boulder-sized particles. Above 2,000 m, the scree slopes are still active, whereas at lower altitudes (e.g. the Ordesa and Añisclo canyons) they have been colonised and stabilised by vegetation. Snow avalanches together with other mass movements form rectilinear canals that cross the forest and develop debris cones.

However, the most characteristic periglacial feature in the OMPNP is the patterned ground, particularly in the Marboré Cirque, above 2,600 m and near relict glaciers of the Monte Perdido Massif. The patterned ground results from the cryoturbation processes, involving the selective displacement of fine and coarse material due to the presence of ice and the development of cracks. Permafrost occurs throughout the Marboré Cirque, although the upper part of the soil thaws in summer, developing an active layer (*mollisol*). Examples of active polygons are evident in the central and western sectors of the Marboré Cirque, mostly on flat areas with poorly drained sandy soils (Fig. 14.5) and at more than 3,000 m on the Marboré Peak, where cryoturbation is a common phenomenon in early autumn. On moderately steep areas, the polygons are replaced by

Fig. 14.4 Little Ice Age moraines in the Marboré Cirque, at the foot of the Cilindro peak. *Photograph* J.M. García-Ruiz

Fig. 14.5 Sorted stone polygons in the Marboré Cirque. *Photograph* J.M. García-Ruiz

Fig. 14.6 The lower Monte Perdido glacier in September 2010. *Photograph* J.M. García-Ruiz

stripes. Gelifluction terracettes are particularly evident in the headwater of the Pardina ravine, where they develop micro-terraces with *Festuca gautieri* on the crest of the risers, growing on remnants of degraded thin soils.

14.3.5 Shallow Landslides and Soil Erosion on Hillslopes: Human Impacts

Deep silty soils have developed on marly limestone outcrops. Such soils are located in the Pardina and Capradiza ravines and near the Góriz Shelter and show relatively recent spatial redistribution because of water and wind erosion. At some sites, the soil is more than 4 m deep, particularly at the foot of small cliffs. The forests that used to cover these soils several centuries ago were burnt to facilitate grazing by transhumant sheep flocks. As in other Pyrenean areas, deforestation of the subalpine belt activated soil erosion and shallow landsliding processes (García-Ruiz and Arbella 1981; García-Ruiz et al. 2010).

14.3.6 Contemporary Glaciers

The north face of the Monte Perdido Massif (Marboré Cirque) still has small active glaciers inherited from the LIA. LIA glaciers developed on both the north- and south-facing slopes of the massif, which has fresh moraines close to the cirque walls. The size of the glaciers has decreased since the beginning of the nineteenth century and some have disappeared, providing evidence for the impact of global warming in the Pyrenees. At the beginning of the twentieth century, the north face of the Monte Perdido Peak had three glaciers with a stepped arrangement controlled by structural benches, the highest of which produced continuous ice avalanches. At the present time, only two thin glaciers remain (Fig. 14.6). The Cilindro–Marboré glaciers, which are located to the west of the Monte Perdido glaciers, have now become small ice patches. Melting has accelerated in the last three decades as a consequence of increasing temperature and decreasing winter snowfall (Chueca et al. 2002; López-Moreno 2005).

14.4 Conclusions

The OMPNP has an impressive relief (3,355 m at its highest point) mostly developed on massive limestone and some marly limestones and sandstones. The thick limestone succession is related to the stacking of south-verging thrust sheets, which favoured the development of (1) vertical cliffs in a series of steps controlled by the different lithological units; (2) deep canyons; and (3) karst landforms and very limited surface drainage, except in the main rivers. The high altitude of the Monte Perdido Massif favoured the development of large glaciers which carved stunning U-shaped valleys flanked by steep walls >700 m high. Most of the preserved glacial deposits belong to recent glacial stages, the LIA being particularly well represented. The high altitude of the Monte Perdido Massif has also favoured: (1) the presence of small glaciers that have significantly receded since the end of the LIA; and (2) the occurrence of active periglacial features, including scree slopes and patterned ground like sorted stone polygons and stripes. Deep soils developed on marly outcrops have been intensively eroded after deforestation.

References

Barrère P (1952) Evolution mécanique et nivation sur les versants calcaires de la haute montagne pyrenéenne. Pirineos 24:201–213

Barrère P (1964) Le relief karstique dans l'Ouest des Pyrénées Centrales. Revue Belge de Géographie 88:9–62

Barrère P (1971) Le relief des Pyrénées Centrales franco-espagnoles. Institut de Géographie, Université de Bordeaux, Bordeaux

Chueca J, Julián-Andrés A, Peña-Monné JL (2002) Comparación de la situación de los glaciares del Pirineo español entre el final de la Pequeña Edad del Hielo y la actualidad. Boletín Glaciológico Aragonés 3:13–41

García-Ruiz JM, Arbella M (1981) Modelos de erosión en el piso subalpino: la degradación de los loess del macizo de Monte Perdido (Pirineo central español). Pirineos 114:35–58

García-Ruiz JM, Martí-Bono C (2001) Mapa geomorfológico del Parque Nacional de Ordena y Monte Perdido. Organismo Autónomo de Parques Nacionales

García-Ruiz JM, Beguería S, Alatorre LC, Puigdefábregas J (2010) Land cover changes and shallow landsliding in the Flysch sector of the Spanish Pyrenees. Geomorphology 124:250–259

Hernández-Pacheco F, Vidal-Box C (1946) La tectónica y la morfología del macizo de Monte Perdido y de las zonas de cumbres inmediatas en el Pirineo Central. Pirineos 4:69–108

Lewis CJ, McDonald EV, Sancho C, Peña JL, Rhodes EJ (2009) Climatic implications of correlated Upper Pleistocene glacial and fluvial deposits on the Cinca and Gállego Rivers (NE Spain) based on OSL dating and soil stratigraphy. Global Planet Change 61:300–312

López-Moreno JI (2005) Recent variations of snowpack depth in the Central Spanish Pyrenees. Arct Antarct Alp Res 37:253–260

Martí-Bono C, García-Ruiz JM (1993) La extension del glaciarismo cuaternario en el Parque Nacional de Ordesa y Monte Perdido. Geographicalia 30:271–282

Nicolás-Martínez P (1981) Morfología del circo de Tucarroya (Macizo de Monte Perdido, Pirineo aragonés). Cuadernos de Investigación Geográfica 7:51–80

Oliva-Urcia B, Moreno A, Valero-Garcés B, Mata P, Grupo Horda (2013) Magnetismo y cambios ambientales en registros terrestres: el lago de Marboré, Parque Nacional de Ordesa y Monte Perdido (Huesca). Cuadernos de Investigación Geográfica 39:117–140

Ríos LM, Frutos E, Barnolas A (1982) Mapa Geológico de España, escala 1:50.000, Hoja 178, Broto. Instituto Geológico y Minero de España, Madrid

Ríos LM, Galera JM, Barettino D, Barnolas A (1989) Mapa Geológico de España, escala 1:50.000, Hoja 146, Bujaruelo. Instituto Tecnológico GeoMinero de España, Madrid

Salazar-Rincón A, Mata-Campo P, Rico-Herrera MT, Valero-Garcés BL, Oliva-Urcia B, Ibarra P, Rubio FM, Grupo Horda (2013) El paleolago de La Larri (Valle de Pineta, Pirineos): Significado en el contexto del último máximo glaciar en el Pirineo. Cuadernos de Investigación Geográfica 39:97–116